Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

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Chapter 9:
Using QUAL Fingerprinting Results to Develop DOC Constraints in CALSIM

Author: Michael Mierzwa and Jim Wilde

9 Using QUAL Fingerprinting Results to Develop DOC Constraints in CALSIM

9.1 Introduction

DWR's statewide operations model (CALSIM) uses an Artificial Neural Network's (ANN) flow relationships to estimate Delta salinity impacts due to its decisions. However, special flow-based constraints need to be programmed into CALSIM if its operations are to take into account other water quality constituents, such as dissolved organic carbon (DOC), or if different Delta geometry is to be studied. Prior CALSIM / DSM2 In-Delta Storage (IDS) studies have used DSM2's ability to track particles with DSM2-Particle Tracking Model (PTM) to develop flow-based DOC constraints for CALSIM II (Mierzwa, 2003a and 2003b). Because of limitations in the previous PTM-based island particle fate - flow relationships, a methodology using DSM2-QUAL fingerprinting was developed to replace the PTM-based approach.

The concept behind both approaches is to develop a flow-based regression that can answer the following question:

> *How much organic carbon from the IDS project islands reaches the urban drinking water intakes?*

This question can be answered by using DSM2 to estimate the volume of water from the islands that reaches the urban intakes and then developing relationships between volume and various flow parameters. The point of this exercise is to examine these various relationships and then determine which one is most useful.

Similar to the particle fate information provided by PTM, QUAL fingerprints estimate the original sources of water at a given location (Anderson, 2002). The previous PTM-based approach had the following limitations:

- Non-release periods were not simulated (even though the equations were used for all time periods),
- Each release period required a separate simulation for each island,
- Particle fate information was extracted only at the end of each 30-day day PTM simulation, and
- Particles were only released during the first 24-hour period of the simulation.

These limitations were addressed in the new QUAL approach. Daily average fingerprinting results were used to develop relationships between daily percent volume of project island water at an urban intake and flow in the Delta that could be easily used by the CALSIM II Daily Operations Model. This chapter describes the methodology used to fingerprint and develop these relationships. The actual CALSIM constraints are not described in this report.

9.2 IDS Background

DWR's Integrated Storage Investigations' (ISI) IDS project linked CALSIM with its Delta hydrodynamics and water quality model (DSM2) in order to evaluate the changes in Delta water quality due to releasing water from the two proposed IDS reservoir islands, Bacon Island and Webb Tract (see Figure 9.1). The goal of the IDS project was to use the two islands as storage facilities to increase drinking water supply while maintaining environmental standards. In order to meet this goal, it was necessary for CALSIM and DSM2 to be used in an iterative process, where CALSIM output was used to generate boundary conditions for DSM2 which was subsequently run to generate Delta water quality conditions. Relationships developed based on the DSM2 fingerprinting results were used to develop constraints for new CALSIM simulations.

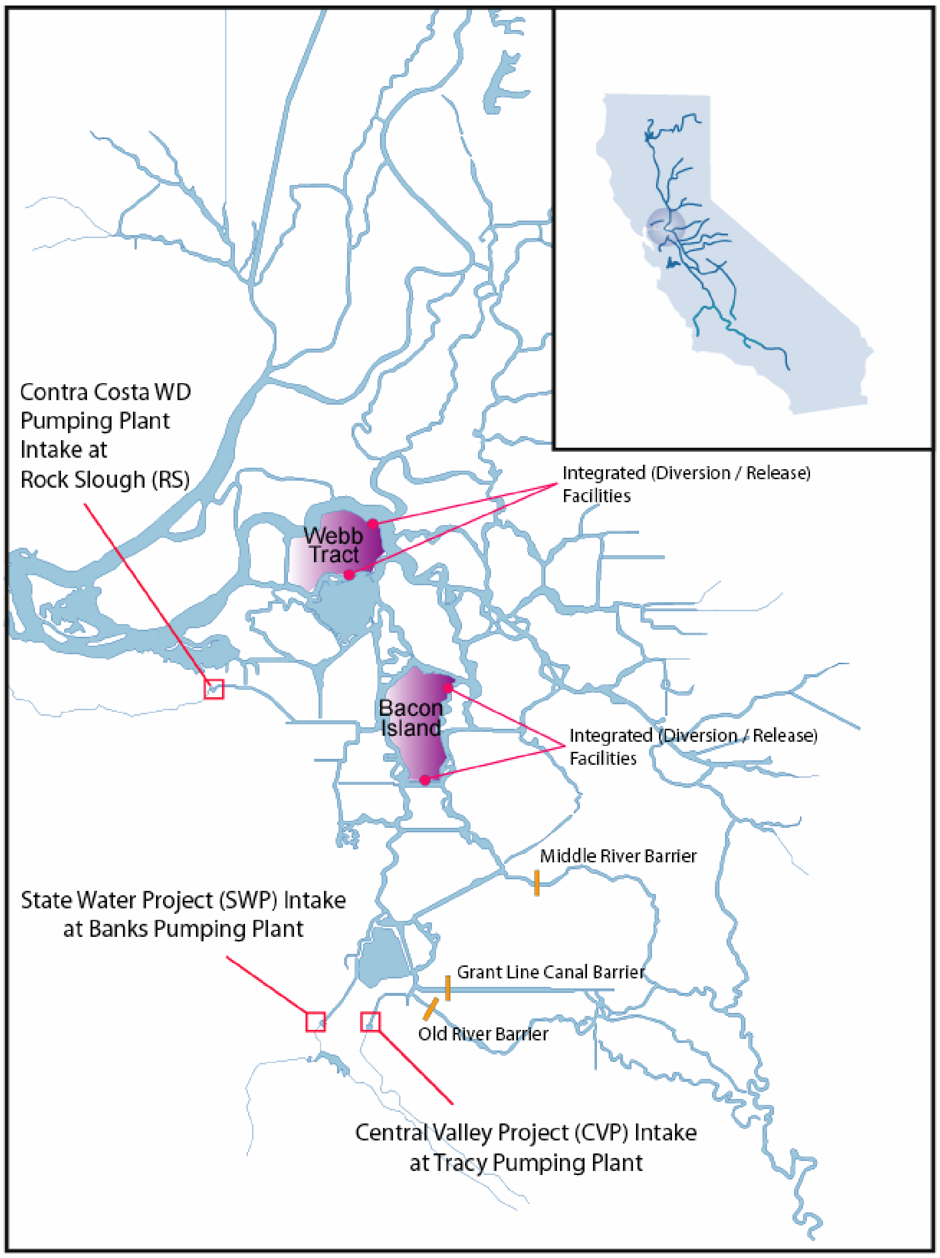

Figure 9.1: Location of Project Islands and Urban Intakes.

As described above (Section 9.1) previous CALSIM-DSM2 DOC constraints were based on an iterative process in which CALSIM provided the operations input to DSM2-HYDRO, and then DSM2-HYDRO's hydrodynamics were used in a series of multiple DSM2-PTM simulations (Mierzwa, 2003a and 2003b). Limitations in the PTM approach lead to using DSM2-QUAL instead of PTM to estimate the amount of water from each of the islands that would reach three nearby urban drinking water intakes: Contra Costa Water District's Rock Slough (RS), the State Water Project's (SWP) Banks Pumping Plant, or the Central Valley Project's (CVP) Tracy Pumping Plant intakes. CALSIM treated Contra Costa Water District's RS and Los Vaqueros Reservoir (LVR) intake diversions as a single node. Since DSM2 did not separate the CALSIM Contra Costa Water District (CCWD) point of diversion to both RS and LVR, no relationship for flow reaching LVR was developed.

9.3 Methodology to Develop Fingerprinting Based Constraints

Using fingerprinting to develop relationships between the volume of water percentage from the island and the Delta flow was a three-step iteration. These relationships were developed based on the results of the second step (i.e. first iteration) of the process. Only the second step involved fingerprinting results. All three steps are shown in Figure 9.2 and described in more detail below.

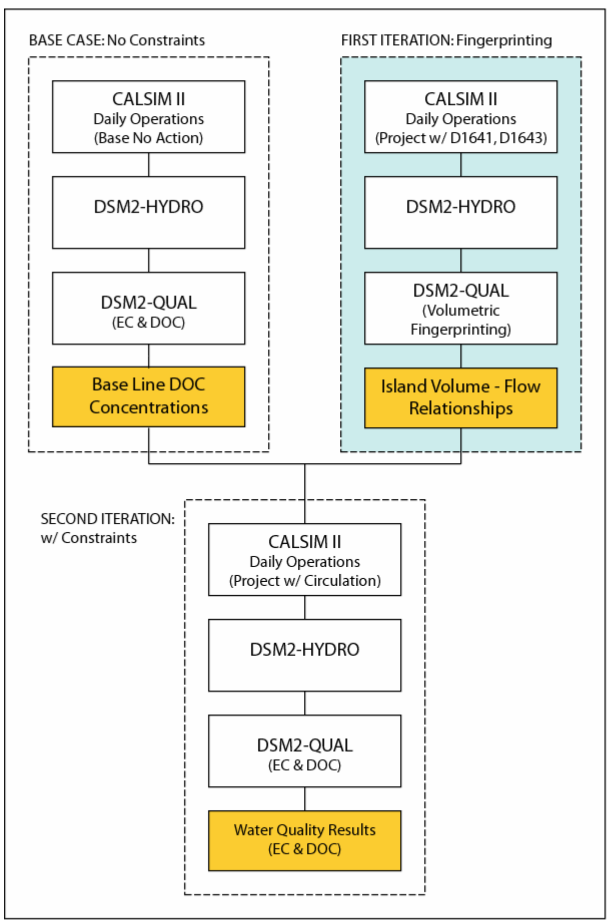

Figure 9.2: Fingerprinting Study Methodology.

9.3.1 Base Case: No Constraints

CALSIM calculated a base case operation of the SWP / CVP system without the presence of the IDS project islands. Since there were no project islands, there was no need for including any DOC constraints on these initial CALSIM simulations. The CALSIM results were then used in HYDRO to generate the stage and flow patterns in the Delta. In turn, the HYDRO results were applied to QUAL to calculate the base line organic carbon concentrations of water in channels adjacent to the islands and at the urban intakes (RS, SWP, and CVP). These results were later used in combination with the fingerprinting-developed relationships developed in the first iteration to form the basis of the DOC constraints in CALSIM.

9.3.2 First Iteration: Fingerprinting

In the first iteration, the IDS project islands were added to the CALSIM simulation, but no organic carbon constraints were used by CALSIM. CALSIM would divert water onto the islands or release water from the islands without considering the impact of these releases on organic carbon loadings at the urban intakes. Stage and flow patterns in the Delta and the diversions and releases from each intake / release facility were modeled in HYDRO. QUAL was then used to calculate the volumetric fingerprint of water at the three urban intakes: RS, SWP, and CVP (see Figure 9.1).

Volumetric fingerprint (Anderson, 2002) studies were used to calculate the percentage of water from each source at a single point of interest. In order to apply a fingerprint to each source of water, it was necessary that every source inflow, including the project island releases, be introduced as a new source. The QUAL fingerprint was applied to this source of water by assigning a unique conservative tracer constituent to it. The sources modeled included: the Sacramento River, San Joaquin River, Yolo Bypass, Eastside Streams (which is treated as a single source in CALSIM), Martinez, Bacon Island, Webb Tract, and agricultural return flows from all other Delta Islands.

Though CALSIM provided separate timeseries for each island's releases and diversions, the IDS plan called for two facilities on each island. Since DSM2 was capable of modeling these two facilities, the CALSIM operations were divided between each island's northern and southern integrated facilities (Figure 9.1) by the following rules:

Diversions	**Releases**
If $Div_{CALSIM} > 2250$ cfs Then	If $Rel_{CALSIM} > 2250$ cfs Then
$Div_{SouthDSM2} = 2250$ cfs	$Rel_{NorthDSM2} = 2250$ cfs
$Div_{NorthDSM2} = Div_{SouthDSM2} - Div_{CALSIM}$	$Rel_{SouthDSM2} = Rel_{NorthDSM2} - Rel_{CALSIM}$
Else	Else
$Div_{SouthDSM2} = Div_{CALSIM}$	$Rel_{NorthDSM2} = Rel_{CALSIM}$

where,

Div_{CALSIM} = CALSIM Total Island Diversion (cfs),
$Div_{SouthDSM2}$ = DSM2 Diversion at Island’s Southern Facility (cfs),
$Div_{NorthDSM2}$ = DSM2 Diversion at Island’s Northern Facility (cfs),
Rel_{CALSIM} = CALSIM Total Island Release (cfs),
$Rel_{SouthDSM2}$ = DSM2 Release at Island’s Southern Facility (cfs), and
$Rel_{NorthDSM2}$ = DSM2 Release at Island’s Northern Facility (cfs).

The above project island integrated facility operation rules can be generalized to state that the majority of the project diversions were taken from each island’s southern facility, while the majority of the project releases occured at each island’s northern facility. The project islands themselves were not modeled since the goal of the fingerprinting simulation was only to estimate the volume of project island water that reached the urban intakes.

The last step in the first iteration was to use the QUAL volumetric fingerprinting results in order to develop island volume - flow relationships for each of the three urban intakes. These relationships along with the DOC results from the base case simulation formed the CALSIM DOC constraints. The fingerprinting results are briefly discussed below (Section 9.4) and the relationships derived from them are described in Section 9.5.

9.3.3 Second Iteration: with Constraints

The second iteration of CALSIM used the DOC constraints developed from the base case organic carbon concentration at the urban intakes and the island volume – flow relationships from the first iteration fingerprinting results. CALSIM limited the releases from the project islands when the volume of water released from the islands and current DOC concentration on the islands was high enough that the additional DOC mass would violate the D-1643 Water Quality Management Plan (WQMP) organic carbon constraints.

These new CALSIM simulations included an additional operational strategy of circulation. The purpose behind this strategy was to dilute the high concentrations on the project islands by diverting water at the southern integrated facility on each island while releasing the same amount of water from the northern integrated facility. The net change in storage on the islands remained unchanged, but high DOC on the islands was reduced. A negative impact of this operation was that the DOC on the islands mixed with the low DOC water in the surrounding channels. The CALSIM DOC constraints still limited the amount of water released during a circulation operation in the same way that they limited regular project island releases.

HYDRO was then used to simulate flow and stage in the Delta based on the new CALSIM operations. The flow and stage results were then used in QUAL to simulate the EC and DOC at the three urban intakes used in the fingerprinting as well as water quality at CCWD’s LVR intake.

The final results of the IDS study that made use of this methodology are described in DWR’s *In-Delta Storage Program State Feasibility Study Draft Report on Water Quality* (2003).

9.4 Fingerprinting Results

As described in Section 9.3.2, each of the inflows into the Delta, including water entering the Delta from DSM2's ocean boundary at Martinez and the releases from the project islands, was assigned a unique conservative tracer constituent and then independently simulated in QUAL. This tracer constituent was arbitrarily assigned a value of 10,000 as recommended by Anderson (2002). The relative contribution of each source at the three urban intakes: RS, SWP, and CVP, was calculated by dividing the contribution from each source by the total contribution of all sources. Since DSM2 conserves mass, the combined concentration from all sources was equal to 10,000.[1]

Examples of selected volumetric fingerprinting results from the IDS study at RS are shown as pie charts (Figure 9.3). Although eight different sources were used in the QUAL simulation, the results were combined into four different sources: IDS project islands, San Joaquin River, Sacramento River, and other. Daily average results for the first day of each month are presented with the monthly average results.

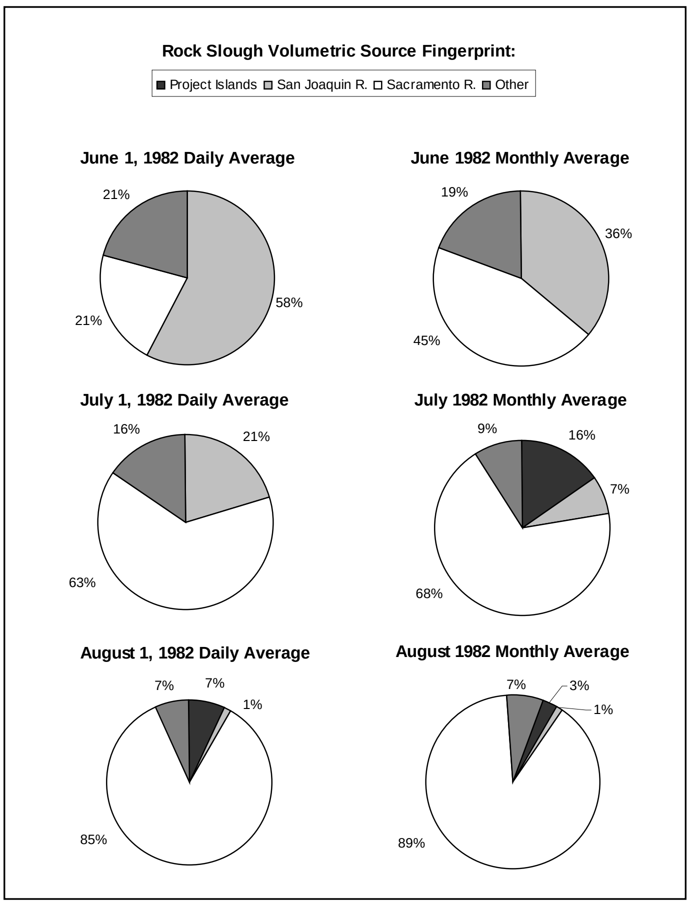

Figure 9.3: Selected Rock Slough Volumetric Fingerprint Pie Charts.

[1] The assumption that DSM2 conserves mass can be verified by using a volume fingerprinting analysis. When a uniform concentration, say 10,000 mg/L, is assigned to every inflow, the sum of the source water concentrations at any point in the Delta will approach the uniform concentration assigned at each of the sources.

The relative contribution of source water at Rock Slough is highly variable by both day and month. For example, for July 1, 1982, Rock Slough source water was 63% from the Sacramento River, 21% from the San Joaquin, and 16% from other sources. None of the water on July 1, 1982 came from the project islands. But for the July 1982 monthly average, only 7% of the water at Rock Slough came from the San Joaquin and 16% of the water came from the IDS project islands. Though values after the release period on August 1, 1982 still showed 7% of the water at Rock Slough as having originated in the project islands, this was still less than the July monthly average of 16%. In this case, a single daily distribution was not a good tool for developing volume - flow relationships.

If only a few sources are being analyzed, area charts are also useful in illustrating the sensitivity of change in the relative contributions of different sources at a given location. Examples of area chart volumetric fingerprinting results for RS, SWP, and CVP from the IDS study are shown in Figures 9.4 – 9.6. In an area chart, instead of looking at a specific or an averaged period of arbitrary length, the relative contribution of each source is stacked in a time series with the other sources. The sum of all the contributions will equal 100%.

For the same July 1982 project island release, the percentage of project island water at Rock Slough quickly increased in July, but slowly trailed off in August through October (Figure 9.4). During the time that the percent of project island water decreased, the percentage of water from other sources remained relatively constant and the percentage of Sacramento River water increased. The area charts show similar trends in the July 1979, 1980, 1981 and 1986 project island releases.

Though the area charts do not provide quantitative relationships, they are easy to generate and are useful in illustrating the temporal response of a few parameters at the same time. A limitation in using area charts is that the plots become very difficult to interpret as the number of time series increases.

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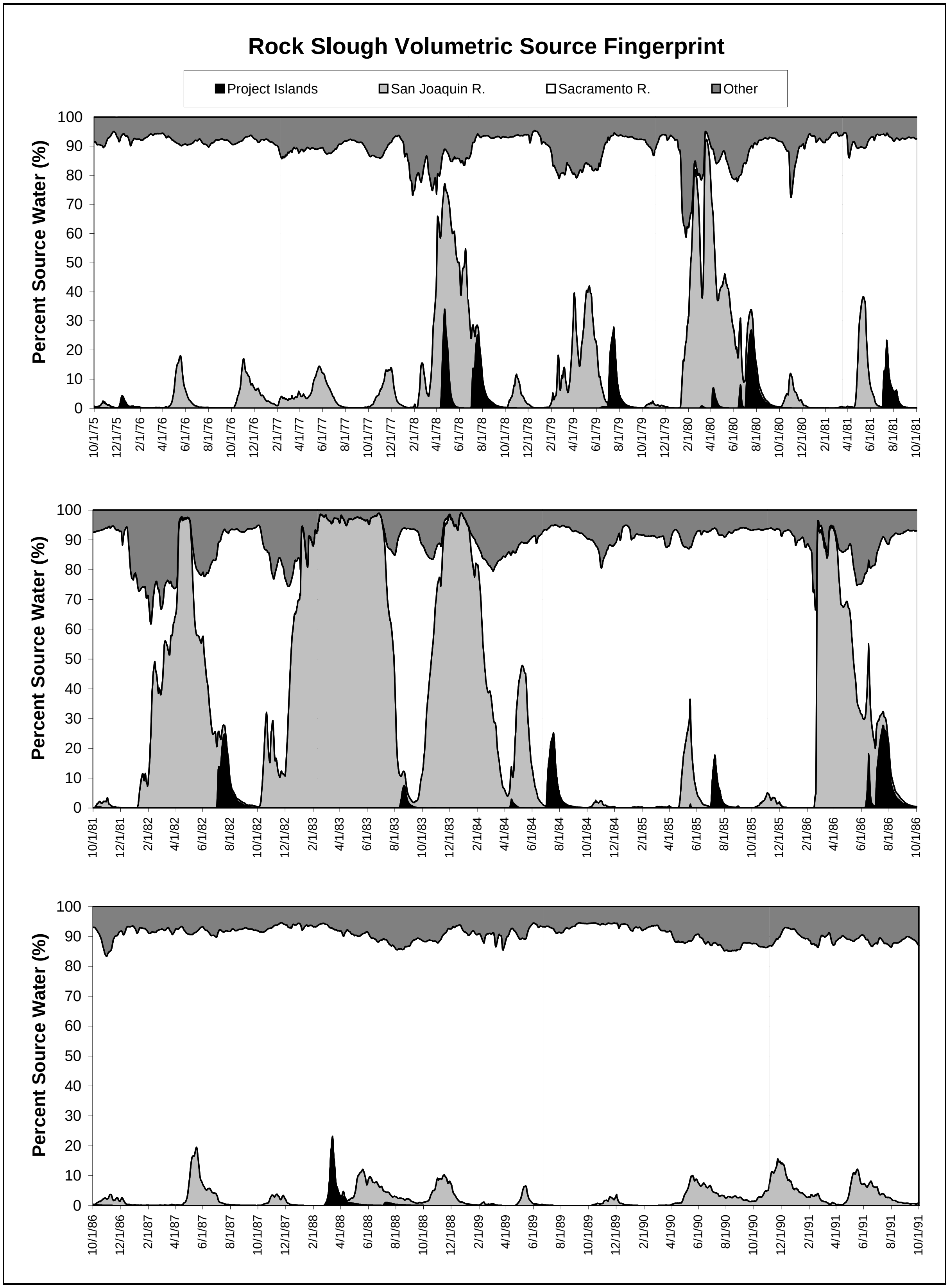

Figure 9.4: Rock Slough (RS) Volumetric Fingerprint Area Chart.

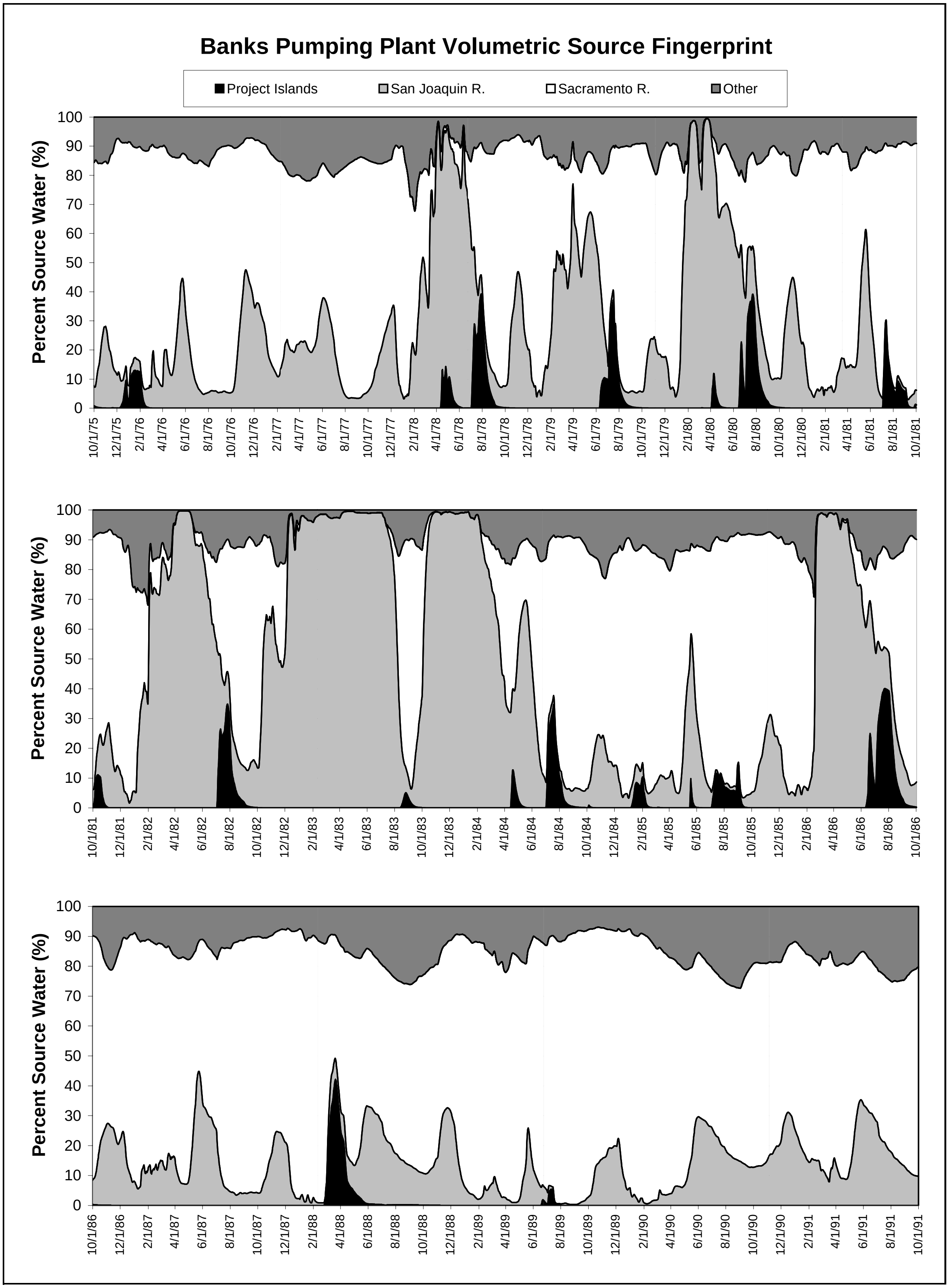

Figure 9.5: Banks Pumping Plant (SWP) Volumetric Fingerprint Area Chart.

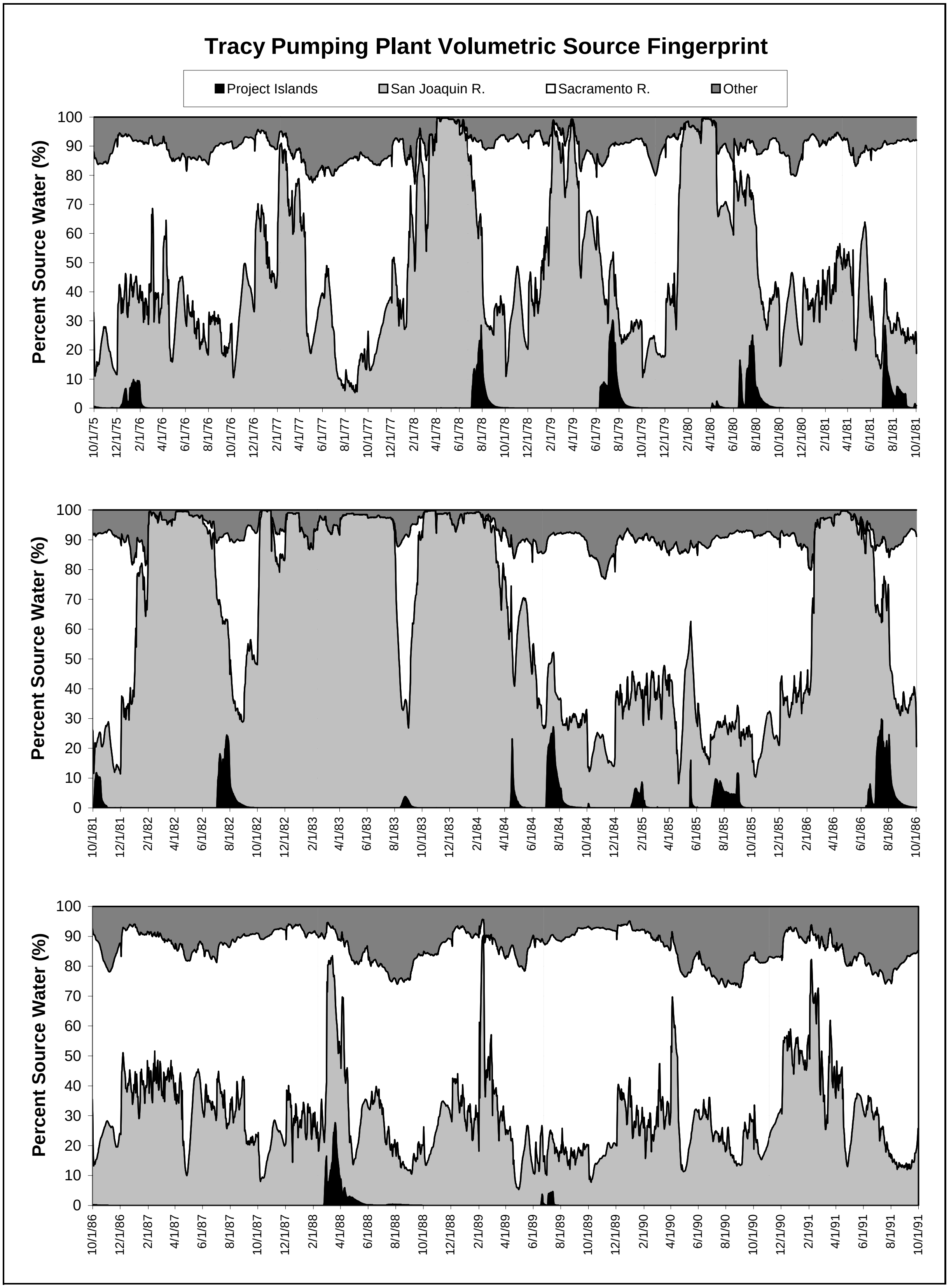

Figure 9.6: Tracy Pumping Plant (CVP) Volumetric Fingerprint Area Chart.

9.5 Island Volume - Flow Relationships

Even though the volumetric fingerprint area charts are useful in illustrating the relative contribution of island water over time at each of the urban intake facilities, the area charts get busy quickly. Since CALSIM independently operated the two IDS project islands, it was necessary to develop separate island volume - flow relationships for each island at all three of the urban intakes. These relationships were developed by examining the response of island volume at the urban intakes to various flow parameters including:

- E/I ratio
- Island releases
- Sacramento River inflow
- San Joaquin River inflow
- Total Delta inflows
- Combined SWP and CVP exports
- Only SWP exports
- Only CVP exports
- Combined CCWD diversions

An example time series of the percent volume contribution of each of the project islands at Rock Slough along with the combined SWP and CVP exports and the San Joaquin River flow (Figure 9.7) illustrates the difficulty in finding a relationship between a single flow parameter and the percentage of island water reaching Rock Slough. Therefore, relationships based on multiple linear regressions were developed for the three urban intakes (Table 9.1).

The length of time that project release water remains in the Delta was important when developing DOC constraints in CALSIM. Water released at the beginning of a release period contributed new organic carbon to the urban intakes. Whereas water released towards the end of a release period or at the beginning of a release period shortly after previous release period needed to account for the accumulation of organic carbon from previous releases. With this in mind, running averages of the releases were used when developing the island volume - flow relationships.

Since this particular study was based on a future level of development, DSM2 assumed permanent South Delta barriers (see *DWR*, 2003 for more information on the configuration and timing of these barriers). No parameter for the operation of these barriers was directly incorporated into the island volume - flow relationships; however, the barriers were indirectly accounted for in the Rock Slough equation by developing four different equations: two from April through November in which the barriers might be operated, and two from December through March when the barriers were never operated. In the April through November equations, San Joaquin River flow was used as a surrogate to identify periods when the barriers would be inoperable due to high flows.

The equations were developed through a trial and error process using the R^2 statistic as a measure of fitness. The variables and range of values used in the equations listed in Table 9.1 are described in Table 9.2. Though a formal scale analysis was not conducted to simplify the equations in Table 9.1, each equation was quickly checked using numbers taken from Table 9.2

and found to yield reasonable results. Time constraints prevented re-entering the historical flow parameters into the equations and performing a statistical analysis on accuracy of the equations to forecast island volume relative to the modeled island volume.

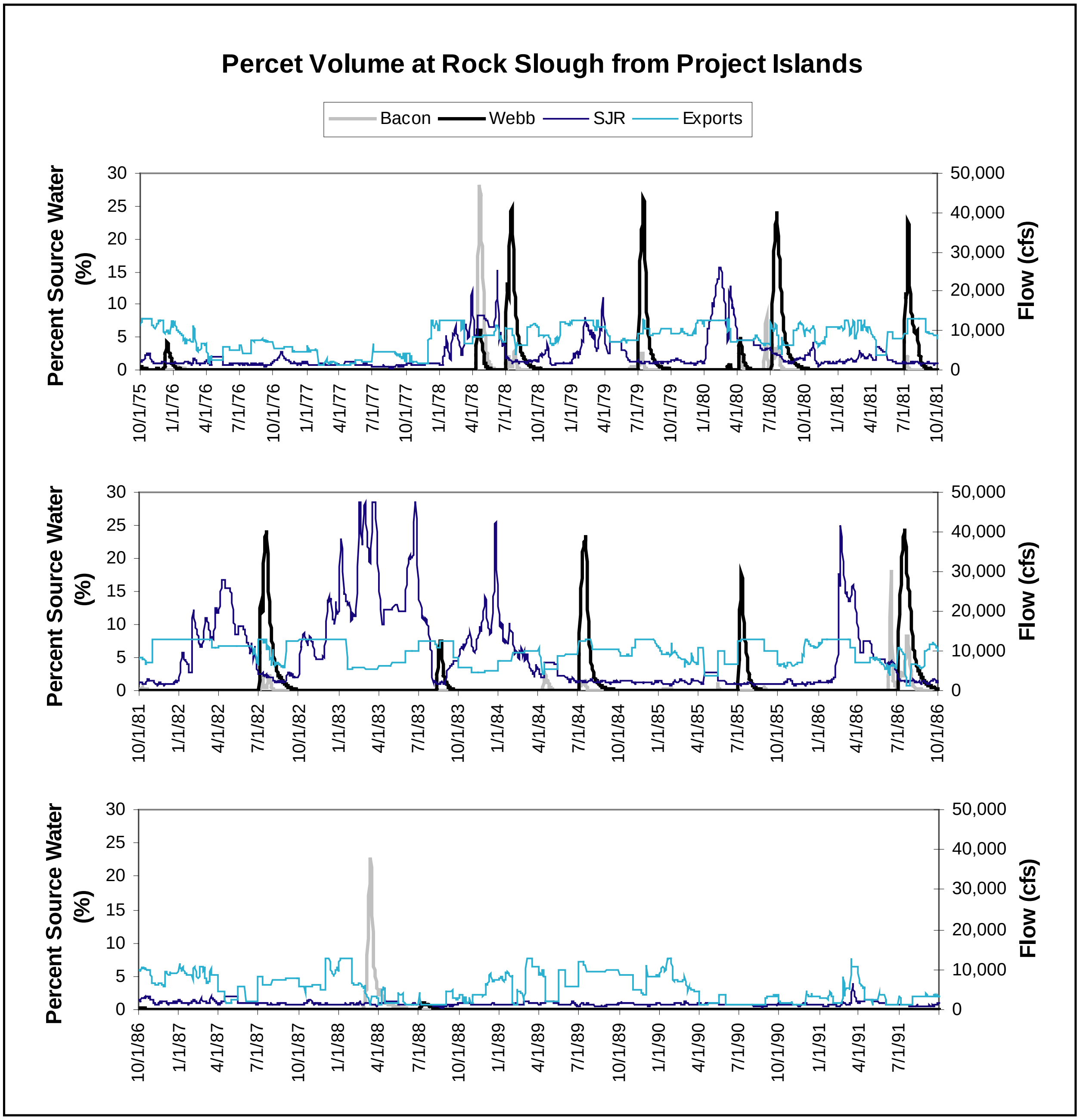

Figure 9.7: Percent Volume at Rock Slough from Project Islands.

Table 9.1: Percent Island Volume - Flow Relationships.

Urban Intake	Island	Relationship	R^2
RS	Bacon	**Apr. – Nov., Q_{SJR} > 8,500 cfs** $V = -1.93\times10^{-3}Q_{Sac} - 1.3\times10^{-3}Q_{SJR} + 1.2\times10^{-3}Q_{inflow} + 1.27\times10^{3}Q_{SWP+CVP} - 4.4\times10^{2}\,E/I - 6.43\times10^{3}Q_{CCWD} + 1.02\times10^{-2}Q_{Bacon,\,20-day\ ave} - 9.79\times10^{6}$	0.84
		Apr. – Nov., Q_{SJR} ≤ 8,500 cfs $V = 0.05$	N/A
		Dec. – Mar., E/I ≤ 0.37 $V = 1.89\times10^{-2}Q_{Sac} + 2.49\times10^{-2}Q_{SJR} - 2.0\times10^{-3}Q_{inflow} - 5.58\times10^{-2}Q_{SWP+CVP} + 7.80\times10^{2}\,E/I - 1.0860\times10^{2}Q_{CCWD} + 1.43\times10^{-2}Q_{Bacon,\,20-day\ ave} + 1.05\times10^{4}$	0.92
		Dec. – Mar., E/I > 0.37 $V = -1.16\times10^{-5}Q_{Sac} + 1.83\times10^{-5}Q_{SJR} + 4.71\times10^{-7}Q_{inflow} - 6.03\times10^{-6}Q_{SWP+CVP} - 1.4\times10^{-1}\,E/I + 5.60\times10^{-4}Q_{CCWD} + 3.36\times10^{-4}Q_{Bacon,\,20-day\ ave} + 1.6\times10^{-1}$	0.88
	Webb	$V = 8.8\times10^{-3}Q_{Webb,\,20-day\ ave} + 8.5\times10^{-2}$	0.90
SWP	Bacon	$V = 2.56\times10^{-4}Q_{SWP+CVP} - 3.6\times10^{-4}Q_{SWP} + 1.9\times10^{-1}\,E/I + 5.2\times10^{-3}Q_{Webb,\,20-day\ ave} - 3.69\times10^{-1}$	0.80
	Webb	$V = -6.54\times10^{-1}\,E/I + 1.13\times10^{-2}Q_{Bacon,\,18-day\ ave} + 4.77\times10^{-1}$	0.70
CVP	Bacon	$V = 6.1\times10^{-3}Q_{Bacon,\,8-day\ ave} + 1.67\times10^{-1}$	0.69
	Webb	$V = -5.2x10^{-05}Q_{SWP+CVP} + 2.01\times10^{-4}Q_{CVP} + 3.07\times10^{-1}E/I + 3.6\times10^{-3}Q_{Webb,\,20-day\ ave} - 2.59\times10^{-1}$	0.79

Table 9.2: Sensitivity of Flow Parameters in Table 9.1.

Variable	*Flow Parameter*	*Range of Values*
E/I	Delta export / inflow ratio	0 – 1
Q_{CCWD}	Contra Costa WD diversions	0 – 600 cfs
$Q_{Bacon,\ 8\text{-}day}$	8-day average of Bacon Island releases	0 – 2,500 cfs
$Q_{Bacon,\ 20\text{-}day}$	20-day average of Bacon Island releases	0 – 2,500 cfs
$Q_{Webb,\ 20\text{-}day}$	20-day average of Webb Tract releases	0 – 2,500 cfs
Q_{SWP}	SWP exports	0 – 8,500 cfs
Q_{CVP}	CVP exports	0 – 5,000 cfs
$Q_{SWP+CVP}$	Combined SWP & CVP exports	1,500 – 13,000 cfs
Q_{SJR}	San Joaquin River flow	1,000 – 50,000 cfs
Q_{Sac}	Sacramento River flow	5,000 – 80,000 cfs
Q_{inflow}	Total Delta inflows	6,000 – 200,000 cfs

9.6 Discussion

Though the actual CALSIM constraints are not described here, the methodology used to develop DOC constraints using DSM2 in an iterative process was illustrated. The process involves several steps. First, CALSIM generates boundary conditions for DSM2. DSM2 is used to calculate the base organic carbon concentrations at Delta urban intakes (i.e. water quality compliance locations). A separate DSM2 simulation calculates the amount of water at the Delta urban intakes that came from the IDS project islands through a volumetric fingerprinting simulation. Finally, island volume - flow relationships from the second DSM2 simulation are combined with both the base organic carbon concentrations and the actual water quality constraints to back calculate the maximum additional loading (and hence volume of water released) from the IDS project islands.

Using CALSIM and DSM2 in an iterative process is based upon several assumptions:

- The island volume - flow relationships can be developed in such a way that they may be easily integrated into CALSIM's decision making process,

- The flow conditions and operations used to develop the island volume - flow relationships will be similar to the flow conditions and operations used in the final CALSIM simulation (i.e. that the CALSIM operations in the first and second iterations are similar), and

- The DOC concentrations associated with water coming from all other sources are not significantly altered by the operation of the project.

Using QUAL fingerprint simulations instead of PTM particle fate to estimate the percentage of volume at each of the urban intakes that came from the project islands addresses all of the limitations of the old PTM based approach, and allows for the development of daily island volume - flow relationship equations. By assuming that the concentration of water from all other sources is not significantly altered by the operation of the project and by using the island volume - flow relationship equations, it is straight forward for CALSIM to reduce the volume of water released from either project island in order to meet the WQMP DOC standard.

Since DSM2 planning studies currently use standardized organic carbon loading for all of the non-IDS flow inputs into the Delta (Suits, 2002), changes in the concentrations of the volume of water from the river and non-project island inflows would be due only to changes in the overall mixing patterns in the Delta. Given that the changes in Net Delta Outflow, SWP / CVP exports, Sacramento River, and San Joaquin River inflows were relatively small over the course of the DSM2 studies (DWR, 2003), the assumption that the concentration of water from all other sources at the intakes was not significantly altered and that the CALSIM volumetric based DOC constraints were valid seems reasonable. However, should this methodology be used in other DSM2 simulations in which the other flow inputs' organic carbon loadings vary with flow, it may be necessary to estimate the change in organic carbon loading at the urban intakes.

Due to project time constraints, instead of holding the basic operation rules of the IDS islands constant, a circulation operation that was not part of the first iteration operations was added in CALSIM's second iteration. Though the circulation operation represented a sufficiently significant change in the flow conditions that were used to develop the island volume - flow relationships, it was assumed that over the course of the 16-year QUAL fingerprinting study that enough different flow and island operations were sampled in order to make reasonable relationships.

When developing the relationships, the operation of the fist protection barrier at Old River at the head of the San Joaquin River was indirectly accounted for by making several conditional regressions for Rock Slough. The operation of the three remaining South Delta permanent barriers was not accounted for in the relationships.

Not all of the water released from the project islands would reach an urban intake in a single day; therefore, in order to account for organic carbon released from the project islands into Delta channels but that did not immediately reach any of the urban intakes, a running average of the releases from each island was used in the regressions. Several different running averages were considered for each intake relationship. This approach was not extended to using running averages for the inflows or exports.

Overall, the use of fingerprinting to develop organic carbon constraints was an improvement over the PTM-based organic carbon constraints. Furthermore, the fingerprinting results themselves aided in answering other hydrodynamic related questions about the operation of the IDS project. Though this methodology was developed with DSM2 planning studies in mind, the idea of linking QUAL volumetric fingerprints with CALSIM operations may lead to developing other water quality constraints in operations models.

9.7 Future Directions

The above methodology was developed over the course of a few weeks in response to requests to improve the previous PTM-based organic carbon constraints used in CALSIM. Though the new methodology allows for more flexibility in developing relationships suitable for use in CALSIM, it can be refined if it is to be used again by considering the following:

- The basic operational rules in the first and second iterations should be kept the same with the hopes that the resulting flow conditions will be about the same.

- An additional iteration to refine the island volume - flow relationships can be added after the first iteration by running a fingerprinting simulation while using organic carbon constraints developed from the first iteration.

- A mass fingerprint simulation should be run in the final iteration in order to check the validity of the assumption that the organic carbon concentration from the non-project island sources is not significantly changed by the re-operation of the system.

- A scale analysis can be performed to reduce the regressions into a less complex form.

- The validity of the regressions can be checked by a full circle analysis, in which a final set of equations can be created using a simulation based on the equations actually used in the production run and then the two sets of equations will be compared.

- Flow weighted averages or some form of autoregressive moving average (ARMA) model can be used to relate the various flow parameters with the contribution of island volume at the urban intakes.

- The operation of the barriers can be incorporated into the equations, either as coefficients on other flow inputs or as a means to divide flow data into smaller samples.

9.8 References

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9.9 Website

The *In-Delta Storage Program State Feasibility Study Draft Report on Water Quality*, which includes the results of this fingerprinting approach, can be found at:

http://calwater.ca.gov/Programs/Storage/InDeltaStorageReports_2003/InDeltaFeasibilityStudies_Jan2004.shtml